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RADIO SECTION

RADIO FIELD-STRENGTH MEASUREMENT

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SUMMARY

The subject of radio field-strength measurement is of direct interest in connection with all applications of radio wave technique. Furthermore, since radiocommunication, broadcasting and, to a lesser extent, navigational aids concern many countries other than that in which the service originates, it is important to ensure that there is international agreement on the methods of measurement used and on the results obtained with the equipment available. The British National Committee for Scientific Radio has been active in this field in connection with the General Assemblies of the Union Radio Scientifique Internationale since 1934, when a comprehensive review of the then existing methods of measuring radio field strengths was presented. Two years later, the National Physical Laboratory conducted a comparison between the various field-strength measuring sets then available in Great Britain for wavelengths between 7 and 1 500 m (40 Mc/s and 200 kc/s). The results of this comparison showed that while in the wavelength band 6 to 10 m (50 to 30 Mc/s) the measurements on different sets agreed to within ± 20% of the mean value, greater divergences were obtained at longer wavelengths; and in the range 100 to 500 m (3 to 0·6 Mc/s) the departures from the mean value of field strength ranged from − 30% to + 60%. An examination by the U.S. Bureau of Standards of a number of commercial equipments for field-strength measurement at wavelengths within the range 200 to 500 m (frequencies 1 500 to 600 kc/s), showed that special precautions were necessary to ensure the attainment of an absolute accuracy within 20%. Apart from the introduction of the use of a shot-noise diode in place of thermal-agitation noise in the first tuned circuit, for adjusting the amplifier in a measuring set to a standard gain, there is no evidence from the published literature that any appreciable advance on the position described above has been made in the past ten years.

What has been done, however, is to improve the technique of field-strength measurement at wavelengths below 10 m (frequencies above 30 Mc/s), and to extend the measuring technique to the shortest wavelengths now in common use for radio applications. These advances have taken place broadly along two main lines; (i) the separation of the calibrating unit from the field-strength measuring set, and its replacement by a method of producing a known field by radiation; and (ii) the replacement of current or voltage measurements which are used at frequencies below about 600 Mc/s, by a measurement of power at frequencies exceeding this value.

With regard to the first, equipment has been developed at the National Physical Laboratory whereby radio field strengths at all wavelengths from about 30 m (10 Mc/s) to about 50 cm (600 Mc/s) can be produced and measured; and the methods are equally applicable to the measurement of continuous-wave and pulse-modulated radiation. The second line of development indicates that for wavelengths below about 50 cm (frequencies above about 600 Mc/s), it is more practicable to measure the power received in an aerial or waveguide system, of which the gain and directional receiving properties are known, than to adopt the more usual methods common at lower frequencies.

At the present time, most of the types of equipment referred to above have been developed on an experimental basis for the use of research laboratories, and there is little commercially produced equipment available even for use at the lowest radio frequencies. While it is considered that field-strength measurement should nowadays be possible to a reliability of the order of 1 or 2 db (say 10 to 25%), the absence of adequate intercomparisons of the techniques on both a national and international basis naturally leads to some lack of confidence on the part of the user who may have important consequences dependent upon the results of such field-strength measurements.

The paper is an official communication from the National Physical Laboratory.

(1) INTRODUCTION

All those engaged in the various modern applications of radio wave technique, and particularly with communication, broadcasting, radar and navigational aids, are concerned with the measurement of radio field strength. Suitable measuring equipment is essential for the establishment and maintenance of new communication circuits, and for the development of antenna arrays, and sending and receiving equipment; those responsible for the provision of broadcasting and television programmes need measuring instruments for determining their useful service area and the interference range of broadcasting stations; the authorities controlling the purchase and installation of radio equipment of all types require appropriate apparatus for checking the performance against the specification with which it is to comply: finally, and by no means least, field-strength measuring equipment is used by engineers and physicists with more academic interests for studying the propagation of radio waves under a variety of conditions along, above and below the earth's surface.

The field strength of a simple, unmodulated, plane-polarized, electromagnetic wave is usually defined as the root-mean-square value of the electric force in the wave. A conductor of unit length set parallel to the electric field of the wave will have induced in it an electromotive force equal to the field strength of the wave. The fact that, at the transmitting station, the radiated waves may be interrupted or modulated for telegraphic or telephonic communication makes no difference to the application of this definition: but the introduction of pulse technique in many recent applications of radio may make it more convenient to associate the measurement with the peak value of the electric force in the wave.

At low and medium frequencies, i.e. long and medium wavelengths, it is customary to limit the above definition to the field at or near to the earth's surface, and to the vertical component of the field in the plane of propagation of the waves. At high frequencies, or short wavelengths, it may be necessary to refer to the field strength in a horizontal or other direction, and at heights above the earth's surface comparable with or greater than the wavelength. As the frequency is made higher still, and we reach the decimetre and centimetre wavebands, the proximity of the earth may become of no significance, and we can make practical use of the field strength of the wave under what are known as free-space conditions.

The practical unit of field-strength measurement is the "volt per metre" (conveniently divisible into millivolts per metre and microvolts per metre as required), and this implies that each metre of antenna set parallel to the electric force in the waves will have induced in it an electromotive force of one volt. The practical measurement of this e.m.f. rests, directly or indirectly upon an observation of the current flowing in the antenna, and, as is well known, the distribution of this current depends upon the frequency in use, the dimensions and shape of the aerial, and upon its surroundings. Over a wide range of frequencies in practical use, it has long been customary to use a symmetrical, vertical, closed loop for the receiving antenna of a field-strength measuring equipment; as the frequency became so high as to

render the use of a closed loop inconvenient, this was replaced by a straight dipole antenna used in the horizontal or vertical position; at the still higher frequencies which have come into use in recent years, this dipole may be supplemented by a reflector, the gain of which must be taken into account in measuring the field strength; while at extremely high frequencies the dipole antenna may be replaced by a waveguide system, the power induced in which is used to determine the field strength of the incoming radiation.

The above definition and statement of the fundamentals of field-strength measurement must really be strictly confined to the case of a single plane-polarized electric wave. It is realized that in practice, there may be present at the receiver two or more waves that have travelled from the transmitter by different paths, and that these waves may be plane or elliptically polarized, that they may arrive at any angle of incidence, and may even be deviated laterally from the true plane of propagation. The practical receiving engineer may require to know the sum of all the incident field components, and in the case of rapidly varying fields (as under fading conditions) he may desire a specification of the field which is maintained under selected conditions. But such knowledge can only be obtained from a synthesis of results obtained by measuring the component wavefields, and in this paper our attention must be confined to the measurement of the field strength in the simplest cases to which our definitions apply, and to the standardization of the measuring equipment used for this purpose.

(2) THE STANDARDIZATION OF FIELD-STRENGTH MEASUREMENT ON AN INTERNATIONAL BASIS

Since radiocommunication, broadcasting and, to a lesser extent, navigational aids concern many countries other than that in which the service originates, it is important to ensure that there is general agreement, on both a national and international basis, on the fundamental technique of field-strength measurement, and on the performance of radio equipment which results from the application of this technique. The British National Committee for Scientific Radio has been active in this field since 1931, when it was asked by the Union Radio Scientifique Internationale (U.R.S.I.) to collect and co-ordinate information on the methods of measuring the strength of electric fields at radio frequencies. The responsibility for carrying out this work was assigned to the Radio Research Board of the Department of Scientific and Industrial Research. With the aid of replies to a circular questionnaire on the subject, received from some forty representatives in ten different countries, a report[1] was presented to the London Assembly of U.R.S.I. in 1934 reviewing the then existing methods of measuring radio field strength. At this meeting the Union decided to continue its study of field-strength measurement, and recommended that the several national laboratories be asked to set up standards of such measurement, and that steps should be taken where possible to conduct international comparisons of these standards. A table indicating the ranges of fields to be measured and the accuracies to be aimed at in the measurements was drawn up, and the recently revised form of this table is referred to later in this section.

Two years later, in 1936, the National Physical Laboratory, working under the auspices of the Radio Research Board, conducted comparison tests between the various field-strength measuring equipments then available in Great Britain for any band of frequencies between 200 kc/s and 40 Mc/s (wavelengths between 7 and 1 500 m). Seven sets of equipment were submitted by five different organizations, and details of the ranges and aerials used are given in Table 1.

Table 1

Set No.	Wavelength range, metres	Type of aerial used
1	6–10	Dipole
2	6–10	Loop
3	6–15	Loop
4	11–800	Loop
5	15–2 000	Loop
6	150–200	Vertical rod
7	800–1 500	Vertical rod

In the case of the three sets covering the wavelength band 6–10 metres (50–30 Mc/s) the divergences in field-strength measurement varied over a range of $\pm 20\%$ relative to the mean value. In the range 10–100 metres (30–3 Mc/s) the divergences between the measured values of field were from -25% to $+13\%$ compared with one of the sets arbitrarily chosen as standard. For wavelengths between 100 and 500 metres (3 and 0·6 Mc/s) the corresponding divergences were from -30% to $+60\%$. The two sets compared on 1 000 and 1 500 metres (0·3 and 0·2 Mc/s) were of the same type and manufacture, and the measurements made with them agreed to better than 10% (i.e. to well within 1 db).

The results of these intercomparisons clearly indicated the need for further study of the problem of field-strength measurement, particularly at medium and high frequencies. The agreement obtained with the very-high-frequency equipments was surprisingly good considering that twelve years ago, the technique of the measurement of field strength at metre wavelengths was not very far advanced.

Some two years later, the results were published[7] of an examination by the United States Bureau of Standards of a number of commercial equipments for field-strength measurement at wavelengths within the range 200 to 500 m (frequencies 1 500 to 600 kc/s). It was shown that at such medium frequencies, special precautions were necessary to ensure the attainment of an absolute accuracy within $\pm 20\%$.

At the 1938 Assembly of U.R.S.I. in Venice,[6] attention was drawn to the advantages and applicability of the radiation method of calibrating field-strength measuring sets at metre wavelengths, but there has naturally been little opportunity for pursuing matters of international comparisons in the intervening ten years. At its first post-war assembly in Paris in 1946, the Union decided to resume its exploration of this subject, and it again recommended that the different national laboratories should endeavour to arrange a comparison of the standard methods which they use. It was further agreed[24] that the precision to be aimed at in standard field-strength measuring apparatus should be as defined in Table 2, which is to be read in conjunction with the accompanying Notes (*a*) to (*e*).

It is desirable to emphasize the use of the word "standard" in the foregoing sentences, as it may clearly prove impracticable to attain the precision specified below in substandard or mobile equipment required for the everyday measurement of field strength.

The following Sections comprise a review of the recent progress made in Great Britain in the development of field-strength measuring equipment. As most of the papers describing this development have already been published in the *Journal*, it is not considered necessary to describe in any detail the methods used at various frequencies. The objective is rather to give an indication of the trend of progress in the subject and an indication of the extent to which the aims represented by Table 2 are being approached.

(3) METHODS USED AT MEDIUM AND HIGH FREQUENCIES

At frequencies below about 20 Mc/s (wavelengths greater than 15 metres) the methods used for field-strength measurements

Table 2

PRECISION OF RADIO FIELD-STRENGTH MEASUREMENTS DESIRABLE FOR STANDARD APPARATUS

Band No.	Wavelength	Frequency	Minimum field			Maximum field		
			Strength, μV/m	Precision of measurement		Strength, V/m	Precision of measurement	
				%	db		%	db
1	Above 2 000 m	Below 150 kc/s	1	± 5	± 0·4	1	± 1	± 0·1
2	2 000–200 m	150–1 500 kc/s	1	± 5	± 0·4	1	± 1	± 0·1
3	200–60 m	1 500–5 000 kc/s	1	± 5	± 0·4	1	± 5	± 0·4
4	60–10 m	5 000–30 000 kc/s	0·1	± 10	± 0·8	1	± 5	± 0·4
5	10–0·5 m	30–600 Mc/s	0·1	± 10	± 0·8	1	± 5	± 0·4
6	50–10 cm	600–3 000 Mc/s	1	± 20	± 1·6	1	± 10	± 0·8
7	10–1 cm	3 000–30 000 Mc/s	1	± 20	± 1·6	1	± 10	± 0·8

Notes.

(*a*) It is desirable to maintain the precision of measurement fixed for the maximum field down to 1 millivolt per metre (1 000 μV/m).

(*b*) It is customary for the apparatus used in Bands 1 to 4 to be equipped with a loop antenna; while in Bands 5, 6 and 7, the antenna system may comprise a rotatable dipole, with or without a reflector. In Bands 6 and 7 also some type of waveguide system may be used, with or without a reflector.

(*c*) In all cases, the type, dimensions and exact arrangement of the antenna system should be described, and particularly in Bands 5, 6 and 7, all components of the polarization adopted for the measurement should be specified.

(*d*) In the very-short-wavelength bands Nos. 5, 6 and 7, the equipment may be required for the measurement of peak fields of pulsed radiation as well as of the root-mean-square field of continuous-wave radiation.

(*e*) It should be realized that the sensitivities attainable in these bands (Nos. 5, 6 and 7) will depend upon the bandwidth of the measuring equipment used.

have been largely based on the use of a tuned closed-loop receiving aerial, connected to a suitable amplifying receiver, with a suitable indicating instrument in the output circuit. The equipment incorporates a local signal generator for injecting a known comparison voltage directly into the loop aerial by one of the alternative arrangements illustrated in Fig. 1. What may

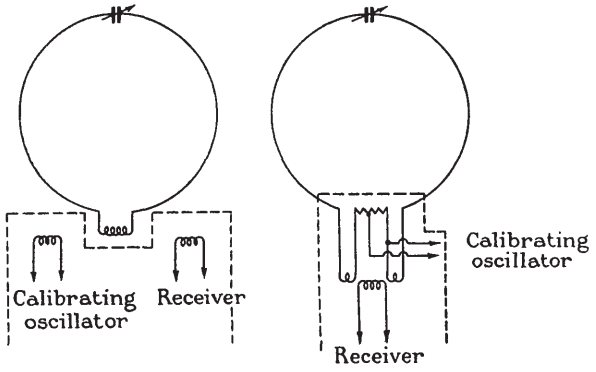

Fig. 1.—Radio field-strength measurement—alternative arrangements for calibration.

be described as commercial or practical types of this equipment have been in use in very limited numbers in this country for the past fifteen or twenty years, and the results obtained with them have formed the basis of such field measurements as have been made during the development of radiocommunication and broadcasting over this period. As the operating frequency is raised, technical difficulties are encountered, first in the use of a loop, the dimensions of which are no longer small compared with the wavelength, and secondly in arranging for the calibration of the equipment with a signal generator built into the receiver. In spite of such difficulties, however, at least two types[4, 9, 14] of measuring apparatus based on the above principles have been developed for use at frequencies up to about 100 Mc/s (wavelengths down to 3 metres). Such apparatus is capable of measuring fields ranging from a few microvolts per metre up to one volt per metre. The accuracy of measurement claimed by those who developed the equipment is from about ± 1 db to ± 2·5 db varying with the actual frequency in use, but since the work described in the previous section, no adequate intercomparisons of performance have been conducted to enable such claims to be supported on a basis of absolute accuracy.

(4) THE CALIBRATION OF FIELD-STRENGTH MEASURING SETS BY RADIATION

With the increasing use of higher radio frequencies an important advance in the technique of field-strength measurement was made by the introduction of a radiation field method of calibrating the apparatus. The basis of this method is the setting up of a known field strength at the position of the aerial of the measuring equipment, by means of a small transmitter of known radiation characteristics. Although originally used with loop aerials at both sending and receiving ends[8] and with vertically polarized waves, several advantages accrue from the use of horizontally polarized radiation and straight dipole aerials, particularly as the frequency is raised from about 60 to 600 Mc/s (wavelengths 5 to 0·5 m).

The principle of the method is illustrated in Fig. 2. The sym-

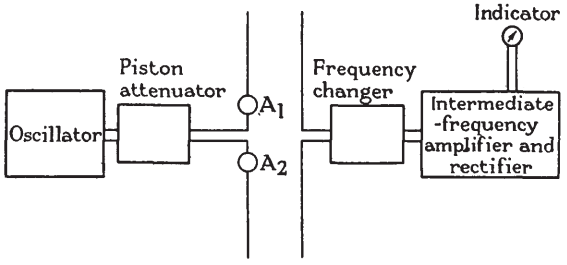

Fig. 2.—Technique of field-strength measurement at metre wavelengths —calibration by standard radiation field.

metry and magnitude of the current in the sending dipole aerial are measured by thermojunctions connected as shown at A_1 and A_2. By suitably choosing the heights and distance apart of the sending and receiving dipoles, the field at the latter can be calculated as the resultant of that due to the waves transmitted directly between the two dipoles, and those which are reflected

from the ground. The electrical characteristics of the ground can be measured independently; but, except at low frequencies, the reflection coefficient of the ground for horizontally polarized radiation at grazing incidence is substantially unity and thus independent of these characteristics.

This technique is very flexible and convenient, and it has been used extensively during recent years, not only for the calibration of actual field-strength measuring equipment, but also for determining the sensitivity of radio receivers at very high frequencies,[16] and for the general study of the propagation of waves.

In order to assess the overall accuracy of this radiation method of measuring field strength, and to link it up with the technique previously used at lower frequencies, a direct comparison was made of the two methods.[11, 12] A known field was set up by the radiation method for the calibration of measuring equipment with a tuned-loop aerial connected as shown in the left-hand side of Fig. 3. At the sending end the experiments were made with

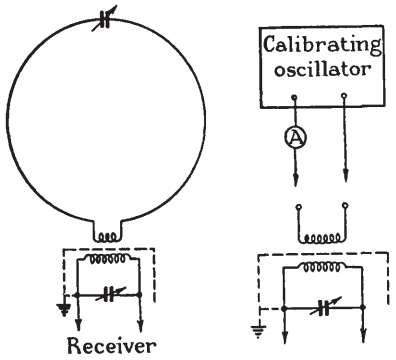

Fig. 3.—Calibration of field-strength measuring set.

both dipole and loop aerials in use as radiators. The tuned-loop at the receiver was then removed and a known current of the same frequency as the radiation was passed directly into the coupling coil to the receiver as shown in the right-hand diagram of Fig. 3. The results of such comparisons are shown in Table 3,

Table 3

COMPARISON OF FIELD STRENGTHS MEASURED BY DIRECT CALIBRATION AND BY THE RADIATION METHOD

Frequency, Mc/s	Wavelength, m	Field strength, microvolts per metre		
		By direct calibration	By radiation from a	
			Loop	Dipole
15	20	2·5	2·5	2·8
37·5	8	5	4·4	5·1

and they indicate that the two methods agree to within about 1 db. This is very satisfactory considering that the radiation field method is not operating under the most favourable conditions at the lower frequency, due partly to the restricted length of dipole that can be used, and partly to the increasing difficulty found in preventing the radiation and reception of vertically polarized waves.

With this confirmation of the reliability of the radiation field technique for field-strength measurement, the method has been developed and used extensively in recent years for measurements at all frequencies between about 30 and 600 Mc/s (wavelengths 10 to 0·5 m). The precision of measurement of fields ranging from a few microvolts per metre up to one volt per metre is considered to be of the order of ± 1 or 2 db.

(5) FIELD-STRENGTH MEASUREMENT AT CENTIMETRE WAVELENGTHS

The techniques described in the previous Section have been extended[19] to much higher frequencies than 600 Mc/s by using circuit arrangements appropriate to the frequency, in particular tuned lines for the resonant circuits in the oscillator units, a crystal detector in the frequency changer and a wide-band intermediate-frequency amplifier. For the aerial system, a quarter-wavelength rod, adjustable in length to cover the whole frequency range, may be used with or without a suitable reflector. Alternatively, a half-wavelength dipole at the focus of a paraboloidal reflector provides a considerable gain in sensitivity, but this is obtained at the expense of flexibility in variation of the working frequency.

It is natural to find from a consideration of the manner in which radar and other developments have taken place on certain specific frequencies, that more attention has been paid to measuring equipment for such frequencies, than for other intermediate parts of the radio spectrum. At a frequency of about 3 300 Mc/s (wavelength 9·2 cm) a field-strength measuring apparatus has been developed[22] with the introduction of several radical changes in technique, one of which is a consequence of a change in measuring technique in an associated sphere. From a recent review[25] of laboratory measuring technique, it is clearly of more direct practical use to measure power instead of current at frequencies above about 300 Mc/s, and considerable developments have taken place in recent years in the use of fine-wire resistors in the form of bolometer lamps for this purpose. Furthermore, at wavelengths of a few centimetres, it is advantageous to use a horn termination to a short section of waveguide as the aerial system both for sending and receiving purposes. The technique of field-strength measurement thus takes the form shown diagrammatically in Fig. 4. At the sending end, a signal

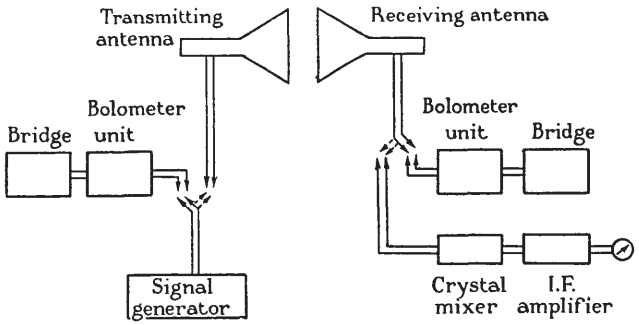

Fig. 4.—Technique of field-strength measurement at centimetre wavelengths.

generator, waveguide, and horn form the standard radiator for setting up a known field for calibration purposes. The power supplied to the antenna system is measured by a bolometer unit and a Wheatstone bridge specially designed for the purpose. At the receiving end, which is the field-strength measuring set proper, the power received in the waveguide system may, if it is sufficiently large, be directly measured in another bolometer unit and bridge as shown. Alternatively, if the power received is too small for this purpose, it can be passed through a frequency changer to an intermediate-frequency amplifier and output indicator as shown in the diagram.

The range of power measurable by suitable bolometer units is from one microwatt up to a few watts, and is easily sufficient to enable a direct overall check of the system to be made, and the gain of the horns, which are identical, to be measured. In

existing equipment, which has been used extensively for the study of wave propagation on a wavelength of 9·2 cm, the range of power measurable in the bolometers was from 1 μW to 100 mW, and the corresponding field strengths concerned were from 0·1 to 50 V/m. By making use of the attenuators in the amplifier, which are calibrated for an intermediate frequency, this range can be extended to much lower field strengths (down to about 50 μV/m).

(6) THE USE OF "NOISE" SOURCES FOR CALIBRATION

One of the difficulties encountered when an attempt is made to apply the straightforward technique of receiver calibration by using a signal generator, or field radiator, with a continuous-wave sinusoidal output at very high frequencies, is that of determining the "absolute" level of the power provided by the signal generator, or field radiator. A different line of attack on the problem, which has been pursued in recent years, particularly with receivers operating at centimetre wavelengths, has involved the design and production of "noise" sources which produce a calculable amount of noise power.

It has been suggested[13,15] that a "noise figure" for a receiver should be defined as "the ratio of the available signal/noise ratio at the terminals of the signal generator to the available signal/noise ratio at the output terminals of the receiver." Thus the sensitivity of receivers at centimetre wavelengths, as expressed by this noise figure (or factor), is measured by comparing the (amplified) noise output of the receiver by itself with the (amplified) output from the receiver when a known amount of noise power is injected at the input.

Thermal or "Johnson" noise from resistors heated to a high temperature, has been used as a noise source, but only relatively small amounts of power can be obtained in this manner, usually, in fact, small compared with the total receiver noise, so that receiver calibration with such a source is not particularly accurate. Considerable attention has therefore been given to the development of "shot" noise generators in the form of diodes and klystron valves,[23] for in this way noise power may be obtained. A diode designed on conventional lines, and operated under temperature-limited conditions, provides a suitable source for the determination of the noise figures of receivers operating at wavelengths greater than about one metre.

The normal measuring technique is to make the diode provide a shot noise current in a known impedance connected to the receiver in place of the aerial impedance. At wavelengths much shorter than one metre there is some difficulty in determining the resistive component of this impedance, owing to the effect of lead inductances. Difficulty also arises because the transit time in the conventional diode becomes comparable with the period of oscillation at the radio frequency concerned; and further, the amount of the effective shot current is reduced and not easily calculable. The former difficulty has been overcome in the "transmission-line diode," which is a noise source in the form of a coaxial transmission line; the inner conductor, which is the cathode, extends along the axis of a narrow-bore metal tube forming both the outer coaxial conductor and the anode of the diode. The shot noise developed in the diode is transferred through matching transformers to either a waveguide or concentric-line load (or loads) connected at one, or both ends of the diode. In practice the most convenient way of using such a noise source is in the resonant condition, with one end of the diode short-circuited, and the other end connected to the receiver across a suitable impedance.

The success of this method of calibration obviously requires a knowledge of the signal/noise ratio in receiving aerial systems, and also of the impedance of such systems.

(7) THE MEASUREMENT OF PULSE-MODULATED FIELDS

So far in this paper, attention has been concentrated upon the measurement of radiation which is either unmodulated, or modulated in some simple and regular manner, such as by sinusoidal tone, for which an expression of the root-mean-square value of the field strength is required. In recent years there has naturally arisen a need for measuring the field strength of pulse-modulated radiation such as is used for radar and communication, or as may arise in the form of an interfering radiation from electrical machinery and ignition systems. Practical steps to meet this need have already been taken by the development of an equipment[20] which is suitable for the measurement of either pulse-modulated or continuous-wave signals in the frequency bands 20–30 and 40–650 Mc/s, (wavelengths 0·46–7·5 and 10–15 m). The overall bandwidth of the receiver has been designed to deal with pulses of various widths and shapes without the sacrifice of too much sensitivity, and a cathode-ray-tube output indicator is used, by means of which the amplitude of the peak or any other part of the pulse can be measured. Although designed primarily for the measurement of the field strength of pulse-modulated signals, it is equally well adapted for continuous-wave signals, and its sensitivity is comparable with that of existing continuous-wave equipments.

The set is normally used with a half-wavelength dipole adjusted for the frequency in use, and over each of the five ranges for which a separate frequency-changer is provided, the sensitivity decreases as the frequency is increased. The minimum measurable field strengths vary from about 3 μV/m at 20 Mc/s to about 500 μV/m at 650 Mc/s for short-pulse signals: for long-pulse or c.w. signals, the sensitivities are about twice the above values. The range of field strength measurable is about 140 db above these minimum values. Relative measurements at any one frequency can be made to within $\pm$ 0·5 db, and the absolute accuracy of the fields measured is considered to be about $\pm$ 2 db. Within these limits of accuracy, the measurements are independent of pulse width for values greater than 0·5 microsec, over a range of recurrence frequencies from 25 to 100 000 pulses/sec.

The equipment, which is readily transportable, has been used for a number of applications, such as the exploration of the polar diagram of a radar transmitting aerial, the measurement of the scattering coefficient of an aircraft, and the study of the interfering radiation emanating from motor-car ignition systems.

(8) CONCLUSION AND ACKNOWLEDGMENT

This paper is intended to give a very brief survey of the position attained in this country in the measurement of radio field strengths. It is seen that techniques have been developed and experimental equipment has been constructed for operation over a large portion of the radio frequency spectrum in use at the present time. When necessary, pulse-modulated fields can be dealt with, and it is likely that any other system of modulation can be used as the occasion may warrant. In some, but all too few, cases the experimental designs have been copied or developed by manufacturers, but there seems to be a marked lack of enthusiasm in this direction, which may possibly be due to the very specialized nature of the work and the fact that the demand for such equipment is very limited. Furthermore, it is clear that a considerable amount of experimental and development work has yet to be carried out if the targets of precision set out in Table 2 are to be approached. Finally, it would appear that the absence of adequate intercomparisons of the techniques on both a national and international basis may lead to some lack of confidence on the part of the radio engineer who may have important consequences dependent upon the results of field-strength measurements.

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